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27 May 2015

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Contract Number:	N00014-14-C-0002
Proposal Number:	P13003-BBN
Contractor Name and PI:	Raytheon BBN Technologies; Dr. Jonathan Habif
Contractor Address:	10 Moulton Street, Cambridge, MA 02138
Title of the Project:	Seaworthy Quantum Key Distribution Design and Validation (SEAKEY)
Contract Period of Performance:	7 February 2014 – 7 February 2016
Total Contract Amount:	$475,359 (Base)
Amount of Incremental Funds:	$440,469
Total Amount Expended (thru 15 May):	$277,858

Attention: Dr. Richard Willis
Subject: Quarterly Progress Report
Reference: Exhibit A CDRLs

In accordance with the reference requirement of the subject contract, Raytheon BBN Technologies (BBN) hereby submits its Quarterly Progress Report. This cover sheet and enclosure have been distributed in accordance with the contract requirements.

Please do not hesitate to contact Dr. Habif at 617.873.5890 (email: jhabif@bbn.com) should you wish to discuss any technical matter related to this report, or contact the undersigned, Ms. Kathryn Carson at 617.873.8144 (email: kcarson@bbn.com) if you would like to discuss this letter or have any other questions.

Sincerely,
Raytheon BBN Technologies

Kathryn Carson

Kathryn Carson
Program Manager
Quantum Information Processing

Report Documentation Page

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Section A. Project Schedule

The Year 2 timeline below identifies the high level SeaKey tasks and their durations.

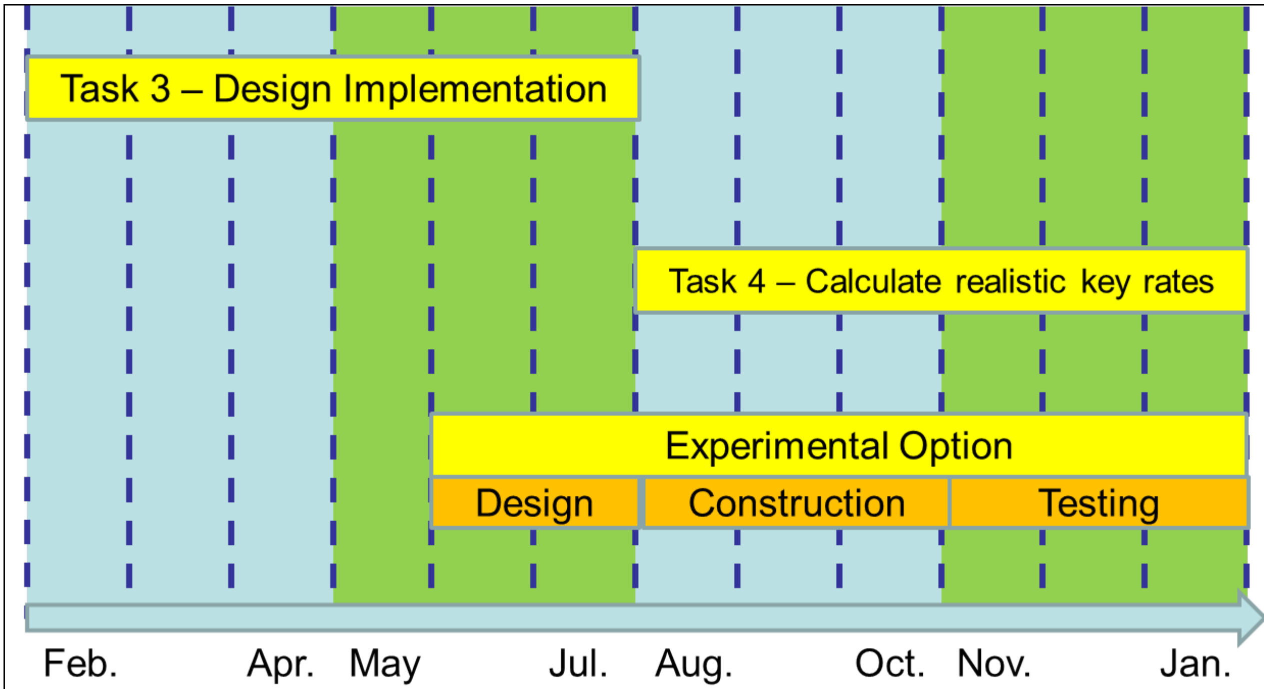

Figure 1: SeaKey year 2 program schedule.

Section B. Technical Progress

SUMMARY

In this report we summarize the technical progress accomplished during the first quarter of the second year of the SeaKey program. Our progress stems from our year 1 work on the program executing tasks 1 and 2. The two major tasks we are executing this year, identified in figure 1, are: (1) designing a proposed implementation for a free-space QKD link optimized for operation in a naval environment and (2) calculating the achievable key rate of the aforementioned QKD link in realistic environmental conditions. This quarter we have begun in earnest the design and analysis of a homodyne receiver for implementing CV QKD.

TECHNICAL RESULTS

The focus of this quarter was having our new staff member, Boulat Bash, get up the speed on quantum key distribution (QKD) literature as well as gearing up for building the model that would inform the experimental evaluation of free-space QKD later this summer. Building a model of the free-space QKD system requires modeling the homodyne receiver as well as the free-space optical (FSO) channel in the conditions relevant to naval operations.

While there is a lot of literature available on homodyne receivers, one has to distill the information out of it that is relevant to building a model suitable for analysis of QKD. Most of the components have been identified, so the next task is putting them together.

The FSO channel model has three components: the extinction model, the background noise model, and the turbulence model. Raytheon Vision Systems (RVS) has provided BBN with the extinction model in the relevant spectrum (1.49µm-4.18µm wavelength) to Monika Patel. The extinction model is based on the data from MODTRAN. In fact, Monika put the data from RVS into an easily accessible format and wrote MATLAB software that calculates key generation rates taking it into account. Background noise model can also be constructed from MODTRAN. Boulat has been in extensive discussions with Matt Thomas from RVS regarding building a dataset of background noise values for the naval operations scenarios, as well as learning about the various background noise models from the literature. Boulat has also been working on the turbulence model using Jeff Shapiro's results. We want to quantify the impact of turbulence on the overlap between neighboring spatial modes, and, ultimately show what impact, if any, does using adaptive optics as well as orthogonal spatial modes (such as Laguerre) has on QKD rate.

Boulat's objective remains building a model that, given the distance separating sender and receiver, can optimize the operational frequency, number of spatial modes (since we should be able to tolerate some overlap), as well as repetition rate (since we should also be able to tolerate some temporal overlap) for the maximum QKD rate.

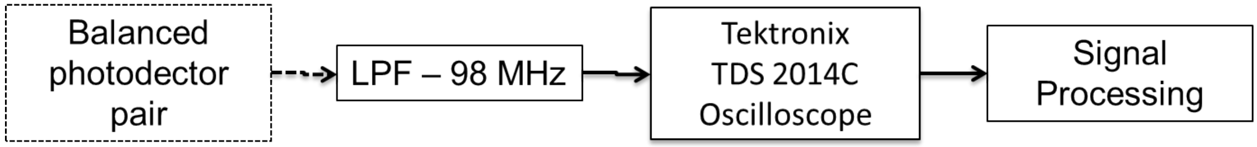

Figure 2: Initial experimental setup of the receiver to baseline the electronic noise in the system and help calculate required LO power for a homodyne receiver. The dotted lines indicate components and connections not yet present in the setup.

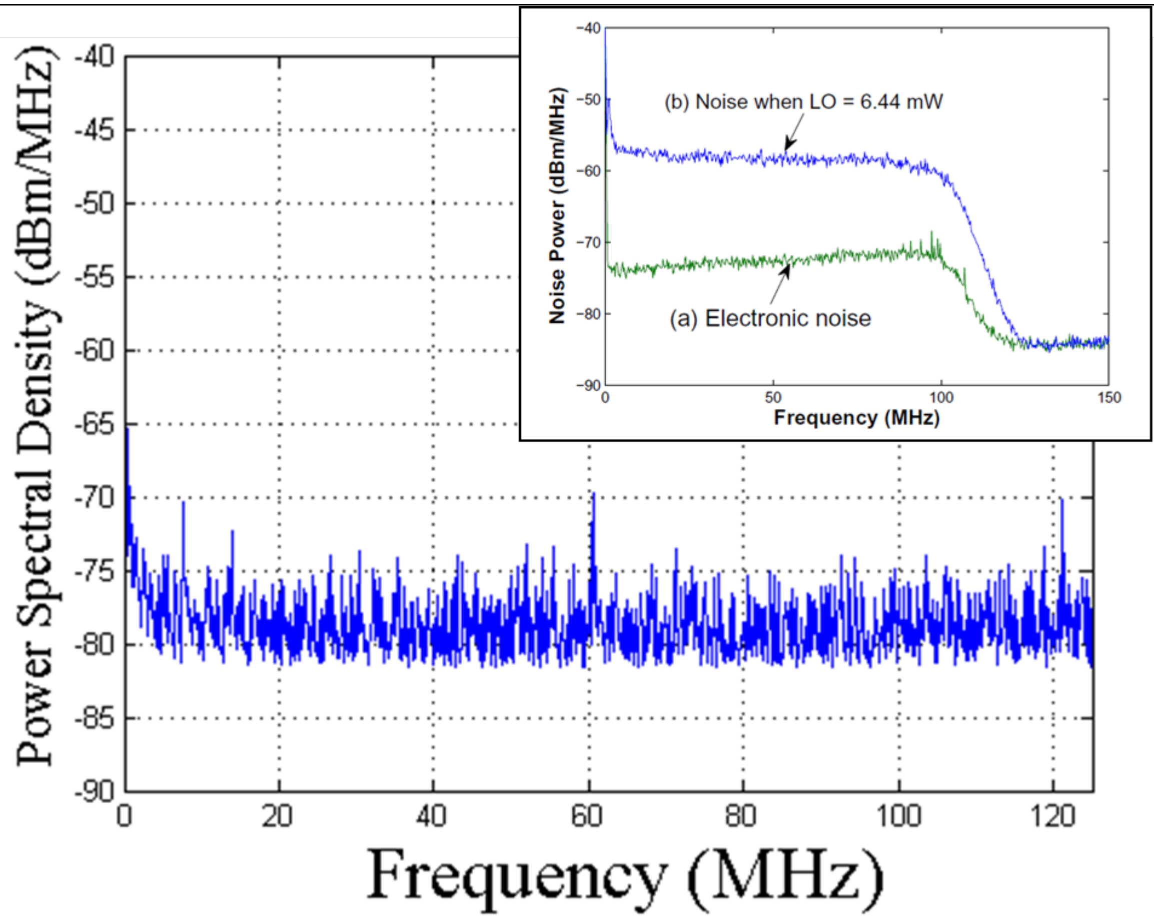

Figure 3: Experimental data taken at BBN demonstrating the noise floor of the receiver electronics that will be used in a homodyne receiver setup. (Inset) data from [1]

To aid in providing context for the theory team, we have begun simple noise measurements in the laboratory to validate the models that Boulat is preparing. Figure 2 shows a high level diagram of the receiver chain for a homodyne receiver. The electrical output from a balanced photodetector pair is sent through a low-pass filter to an oscilloscope. The time-domain oscilloscope trace is captured, and the power-spectral density is computed from the Fourier transform of the autocorrelation function of the signal. Figure 3 shows the computed power-spectral density. To compare our noise floor against published results we have shown in the inset of fig. 3, data taken from [1]. In our experimental setup we have not yet connected the balanced photodetector pair to the scope input. Our next step will be to re-measure the PSD with a detector hooked up to the input. Subsequently, we will add LO power to the detector pair, and measure the required power to achieve shot-noise limited performance of the receiver.

[1] Y. Chi, B. Qi, W. Zhu, L. Qian, H. Lo, S. Youn, A. I. Lvovsky and L. Tian, "A balanced homodyne detector for high-rate Gaussian-modulated coherent-state quantum key distribution," New J. of Physics **13** (2011) 013003.

NEXT STEPS

In the next quarter we will be specifically evaluating the published noise specifications of balanced photodetector pairs. These values will provide the requirements for LO power at the receiver, as well as help define fundamental limits on the key exchange rate achievable [1]. Continuing forward we will include non-idealities that were identified in year 1 of the SeaKey program, such as loss and turbulence in the link.

Section C. Problem Areas – Identification

There are no anticipated problems or issues to report at this time.

Section D. SEAKEY Financial Update

Financial Chart reflecting Year 2: